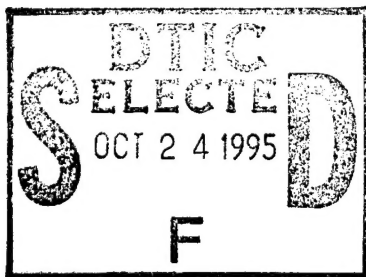# NATIONAL AIR INTELLIGENCE CENTER

PRELIMINARY STUDY ON EFFECTS OF THRUST VECTORING

by

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PRELIMINARY STUDY ON EFFECTS OF THRUST VECTORING

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Abstract: With respect to the thrust vectoring technique adopted in aircraft, the paper is a preliminary study on the pneumatic properties, aircraft performance, and maneuverability after applying a two-dimensional nozzle. Some conclusions are obtained.

Key words: two-dimensional nozzle, thrust vectoring, hyper-torus quantity, maneuver stability, and agility.

INTRODUCTION

In close combat of next-generation fighter aircraft, this is mainly determined by the aircraft performance and flight quality in the post-stall status. At this stage, the efficiency of the pneumatic maneuvering plane is very low, even being unable to control the aircraft; therefore, thrust vectoring control should be adopted in abnormal cases of mobility in the post-stall status.

Due to the application of thrust vectoring, the post-stall mobility becomes possible, thus further expanding the flight envelope. Thus, the flight envelope expands toward the post-stall region.

From trends in developments, the nozzle applying the thrust vectoring technique is mainly a two-dimensional nozzle. Aircraft controlled by thrust vectoring can be subdivided into aircraft completely controlled by thrust vectoring, and aircraft partially controlled by thrust vectoring. The controllability of the former is much higher than that of the latter, with more safety, convenience, simplicity, and economy, and more outstanding mobility and agility. Because of constraints at the technical level, in most cases, as presently adopted, is control of partial thrust vectoring. However, we can predict that full control of thrust vectoring should be adopted in future aircraft [1].

Thrust vectoring is realized with a two-dimensional nozzle. To deeply study thrust vectoring, we should study the effects of a two-dimensional nozzle as regards to the pneumatic properties, performance, and flight qualities of an aircraft.

I. Variations in Lift and Drag Properties of Aircraft

The interference between the aircraft engine thrust nozzle opening and the fuselage has a considerable effect on aircraft flight performance. With different structures at the rear of the fuselage, there are differing drag percentages. In several typical dual-engine fighters, the engines typically account for

20 to 30 percent of total aircraft length; however, engine drag accounts for 38 to 50 percent of total aircraft drag. One-half of the drag due to the rear fuselage comes from disadvantageous interference and drag from different pressures in the rear fuselage range. By using a two-dimensional nozzle, interference drag and pressure difference drag can be considerably reduced during subsonic flight. Another very important aspect is that the two-dimensional nozzle itself not only contributes to the aircraft lift, but also induces the hypertorus quantity on the wings (in the trailing edge of the wings, along the rear as the nozzle ejects high-speed gas flows, thus the induced winding flow along the wing surfaces is the hypertorus quantity), thus further adding to the lift, and at the same time lowering the drag caused by lift [2]. (A two-dimensional nozzle is a rectangular shaped nozzle. It is considered that the lateral-direction flow field is homogeneous, like a two-dimensional wing; therefore, this is called a two-dimensional nozzle. Compared to the axisymmetric nozzle, structurally the two-dimensional nozzle is easily designed and the maneuver for turning the thrust direction is simple.) Therefore, in subsonic flight situations, the external drag of a two-dimensional nozzle is less than for an axisymmetric nozzle. With the same width-to-height ratio of the two kinds of nozzles, there are different resistances at the rear fuselage. When there are identical drag values for the two, the height of the rear fuselage in the case of a two-dimensional nozzle is at least twice that for an axisymmetric nozzle.
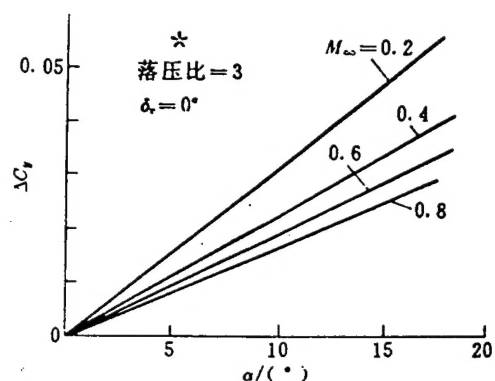
Fig. 1. Effect of angle of attack on
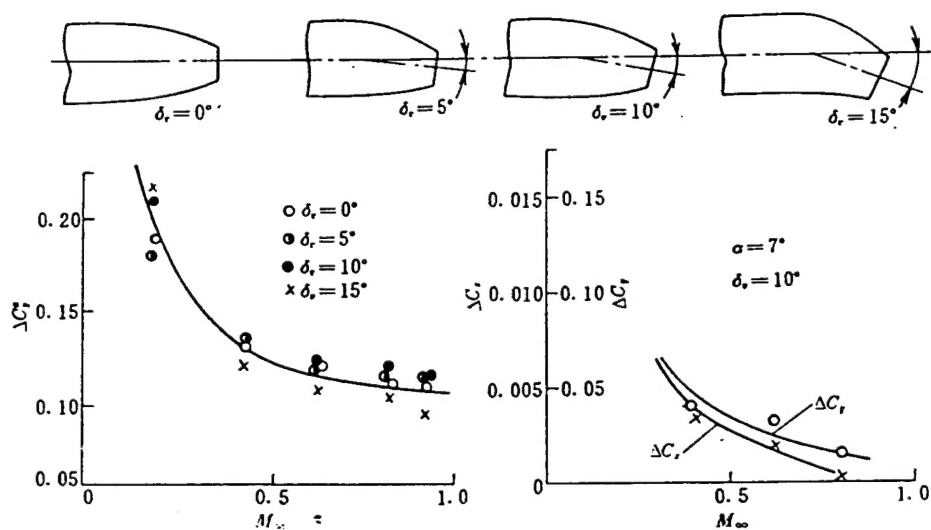lift due to hypertorus quantity
KEY: * - ratio of pressure drop

Fig. 2. Effect on M number with respect to lift due
to hypertorus quantity

Figs. 1 and 2 show the effect of the hypertorus quantity on
lift. From Figs. 1 and 2, during low speed the gain in lift is
very large. With an increase in M number, the lift gain becomes
small. When the angle of attack alpha is between 0 and 14deg,
the lift gain is a linear function of the angle of attack alpha.

Now, we qualitatively analyze the drag variations on the

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aircraft, including the effect of the hypertorus quantity. With
a constant M number, it is required that aircraft always can
obtain the required total lift coefficient at any thrust vector
angle. Due to the existence of the hypertorus quantity, the
angle of attack on the wing can be correspondingly reduced, so
that the induced drag is reduced. To match the torque generated
by thrust vectoring, a deviated canard wing is required, thus
increasing the drag somewhat. However, by comparing the canard
wing with the aircraft wing, as due to increased drag due to
canard wing deflection, and the reduction in induced drag on the
wing, the former is much smaller. Besides, due to the
restoration of thrust, the thrust loss is reduced. The result is
a reduction in total drag. From the above discussion, we know
that the drag variation will be apparently different whether or
not we consider the effect of the hypertorus quantity. When
considering the hypertorus quantity, the maximum lift coefficient
is apparently increased, however the lift-caused drag is reduced
apparently.

TABLE 1. Variation of Drag on Rear Fuselage After
Adopting Two-dimensional Nozzle

机　种 1	F－15	B－1	V/STOL	F－18
2 $\Delta C_{x后}$ (%)	−11	− 25	−30	−23

KEY: 1 - aircraft model　2 - [subscript] rear fuselage

TABLE 2. Variation of Cruising Range After Adopting
Two-dimensional Nozzle

机 种 *	F—15	F—111	V/STOL	YF—17
ΛL (%)	+2.0	+6.8	+21.0	+7.0

KEY: * - aircraft model

II. Variation of Cruise Performance of Aircraft

Table 1 shows the drag variation at the rear fuselage by
adopting a two-dimensional nozzle and by adopting the
axisymmetric nozzle in the aircraft. The table lists the
variation situations of several models of typical aircraft.
Reduced drag will increase the flight range. Table 2 shows the
variation situations of flight range for several aircraft models
[3]. Due to the problem of data source, it was not possible to
coordinate Tables 1 and 2 completely.

III. Variation of Aircraft Mobility Performance

Above, the effects of the hypertorus quantity was discussed.
If the span to height ratio of a thrust-vectoring nozzle (two-
dimensional nozzle) becomes larger, the gas exhaust range along
the trailing edge of the wing is increased, thus further
increasing the effect of the hypertorus quantity.

The increased persistent speed and the instantaneous turning
rate are upgrading the aircraft mobility. For example, an
increase in the maximum limits shifts the left boundary in
Fig. 3, thus upgrading the turning curvature of the aircraft and
reducing aircraft drag, so that the persistence turning boundary
curve moves upward, thus increasing the persistence turning rate

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of the aircraft. As indicated by the computation in reference
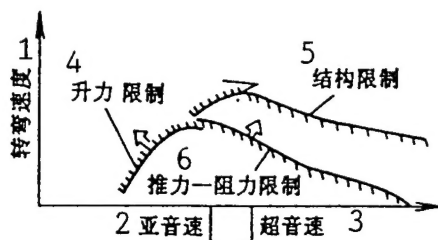[4], with respect to the aircraft having control with thrust

Fig. 3. Effect on turning rate due to thrust vectoring
KEY: 1 - turning rate   2 - subsonic speed
3 - supersonic speed 4 - limitation by lift
5 - limitation by configuration 6 - limitation by
thrust/drag

vectoring, not withstanding how fast is the initial aircraft

speed, the time required to turn the aircraft 180deg is

apparently smaller than for other craft; these planes include

conventional aircraft, the airplanes for reduced rate of turn,

and aircraft controlled by direct force. Due to the greater

increase in the instantaneous turning rate, the aircraft agility

is apparently upgraded; this is more advantageous to air combat.

During low speeds, the efficiency of the pneumatic maneuver

plane is very low. On a number of occasions, malfunctions may

occur. At this point, thrust vectoring is a very effective means

of increasing stability and maneuverability of the aircraft at

low speeds. Fig. 4 indicates a case when M less than or equal to

0.25 for a YF-17 aircraft; the aircraft pitch torque generated by

thrust vectoring consistently maintained constant pitch

acceleration of the aircraft. This capability is very important

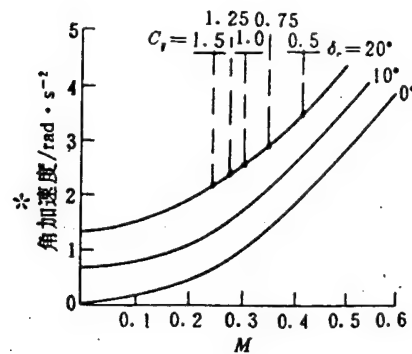in maintaining the attitude during large angles of attack for an

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Fig. 4. Effect of thrust vectoring
on pitch acceleration
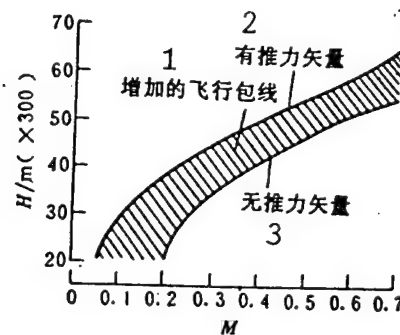KEY: * - angular acceleration

Fig. 5. Effect on flight due to thrust vectoring
KEY: 1 - expanded flight envelope   2 - with thrust
vectoring   3 - without thrust vectoring

aircraft at low speeds. This is also a necessary means of post-
stall maneuvering of the aircraft.

In the case of F-15s, after M less than or equal to 0.4,
since the velocity head is relatively low, the pitch maneuvering
torque generated by the vertical rudder is reduced. Now by using
thrust vectoring control, the pitch effectiveness can be almost
doubled. Therefore, the aircraft flight envelope extends
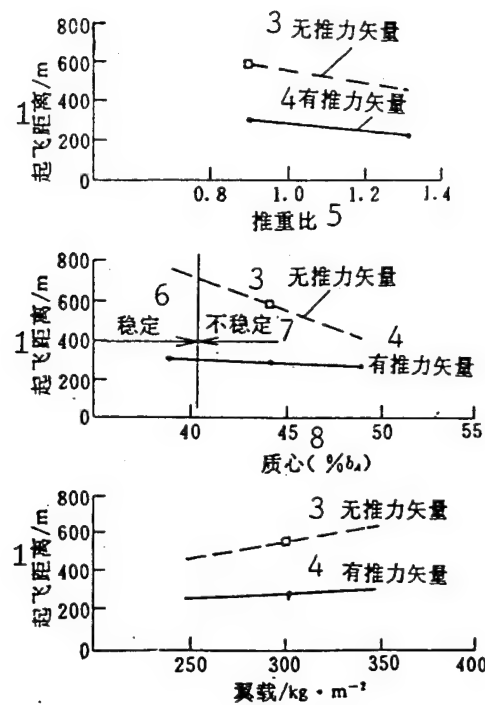leftward, as shown in Fig. 5.

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Fig. 6. Effect on takeoff roll distance
of thrust vectoring
KEY: 1 - takeoff distance   2 - wing loading
3 - absence of thrust vectoring   4 - with thrust
vectoring 5 - thrust to weight ratio   6 - steady
7 - nonsteady 8 - mass center

IV. Variation of Takeoff and Landing Performance

A requirement of tactical techniques of the next-generation
fighter craft is to reduce the distance needed for takeoffs and
landing as much as possible. In particular, this requires the
capability of takeoffs and landings on runways or short decks on
an aircraft carrier with damages caused by enemy bombs. The
running distance of such aircraft should be less than 400m.
Since the thrust to weight ratio of the aircraft is larger, the
problem of short takeoff distances is not as striking as that of

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short distance landings. Especially for aircraft with thrust

vectoring control, the takeoff distance is shorter. By relying

on thrust vectoring control, when the speed is very low, the

pitch thrust vector deflects upward so that the front wheel of

the aircraft is lifted. With the lowered deflection thrust

vectoring, the aircraft leaves the ground very quickly. The

short-distance landing requires that an aircraft should have high

lift and drag, at the same time.

Fig. 6 shows the result of the aircraft model on the same

principle [5]. The aircraft has a canard configuration with

delta wings, but only with a pitch thrust vectoring control. The

figure shows the effects on takeoff distance due to the thrust to

weight ratio, position of the center of mass, and wing loading of

the aircraft. The thrust to weight ratio is 0.89; the position

of mass center is $44\%b_A$; the wing loading is $302\,kg/m^2$, with dry

runway, 0m sea level, and ambient temperature: 15C. From Fig. 6

we can see that with different thrust-to-weight ratios, thrust

vectoring nearly halves the takeoff and landing roll distances at

different thrust to weight ratios. While moving rearward the

mass center, the roll distances are slightly decreased, but much

smaller than the case without thrust vectoring control of

aircraft. With increased wing loading, the takeoff roll distance

is increased. For comparison, the increase in roll distance is

relatively large in the case of the absence of thrust vectoring

control of the aircraft.

Thrust reversal can considerably shorten the landing roll

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distance of aircraft, and is not sensitive to the runway status.
Fig. 7 shows the situations of F-15s. From Fig. 7, thrust
reversal can reduce landing roll distances by approximately two-
thirds without being related to total aircraft mass. Whether for
dry or wet runways, the roll distance does not change,
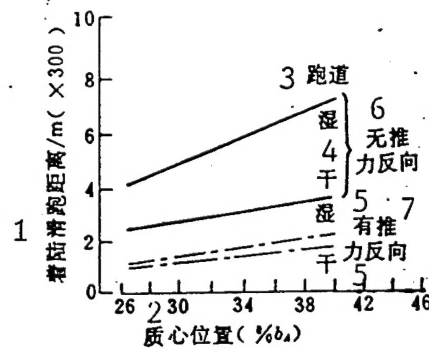apparently.

Fig. 7. Effect on landing roll distance of thrust
reversal
KEY: 1 - landing roll distance   2 - position of
mass center   3 - runway   4 - wet   5 - dry
6 - without thrust reversal 7 - with thrust reversal

TABLE 3. Variation of Landing Roll Distance AFter
Adopting Thrust Vectoring

机 种 1	F－111	YF－17	2 先进飞机
着陆滑跑距离 3 减小量（%）4	14.4	11.0	50.0

KEY: 1 - aircraft model   2 - advanced aircraft
3 - landing roll distance   4 - percentage of
reduction

Table 3 shows a comparison of variation of landing roll
distance for several models of aircraft by using thrust vectoring
[3].

From Table 3, when thrust vectoring is used for controlling an aircraft currently deployed, the decreased magnitude of the landing roll distance is approximately the same, not very significant. The reason is the following: when applying thrust vectoring control, at the same time a canard wing should be installed to coordinate the torque generated by thrust vectoring. However, the maneuverability of the canard wing is not large. In addition, the size and position of the canard wing are restricted by the original aircraft configuration.

V. Conclusions

From the foregoing descriptions, after an aircraft is brought under thrust vectoring control, many aircraft performance indicators are upgraded, to differing extent. Since the existence of the hypertorus quantity, the drag is decreased with a gain in aircraft lift; this is especially significant at low speeds. Due to the reduced overall aircraft drag, the navigation range is increased. Thrust vectoring control increases the persistent turn rate and the instantaneous turn rate of the aircraft, thus considerably upgrading aircraft agility. Especially at low speeds, thrust vectoring control greatly upgrades the aircraft maneuverability and stability, thus considerably upgrading the close air combat performance of the plane. By using thrust vectoring control, the roll distance of the aircraft is decreased; the takeoff roll distance is much more decreased than the landing roll distance. Only by adopting the

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reversing thrust vectoring control can the landing roll distance
be apparently reduced. With complete thrust vectoring control,
the landing roll distance of an aircraft is decreased very
significantly.

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